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Flood moderation by large reservoirs in the humid tropics of Western ghat region of Kerala, India

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Abstract
Kerala State located in the humid tropics receives an average rainfall of 2810 mm. On an average 85% of this rainfall is received during the two monsoons spread from June to November. Midland and lowland regions of several of the river basins of Kerala experience severe flood events during the monsoons. Idamalayar hydro-electric project (1987) in Periyar River basin envisages flood control apart from power generation. This paper analyzes the flood moderation by Idamalayar reservoir considering the storage regime (inflow and outflow) which is subjected to a strong inter annual variability. The role of Idamalayar reservoir in controlling the monsoon floods is analyzed using daily data (1987-2010). The results of analysis show that the flood moderation by the reservoir is 92% when water storage is less than 50%. The reduction is 87% when reservoir storage is between 50 to 90% and moderation reduces to 62 % when the reservoir storage is above 90%. Non-parametric trend analysis of fifty years of hydrologic data shows a reducing trend in inflow and storage during south-west monsoon which reduced spill and subsequent flood events during north-east monsoon.

Keywords: Flood moderation; Humid tropics; Reservoir storage; Return period; Spill.

1. Introduction

Kerala State is situated in south-west India. Rivers of the state originate from the steep high lands of the Western Ghats on the east, flow through the mid land and lowland terrains and finally join the Lakshadweep Sea. The physiography of this humid tropical region and intense monsoon rains cause floods in July- August, almost every year.

Periyar river basin with an areal extent of 5398 sq. km. is the second largest river basin in Kerala. The average annual rainfall of the basin is 2810 mm, estimated using the data from 54 rain gauge stations distributed in and around the basin [1, 2]. Intense rainfall during the monsoon periods are very common, causing floods in the midland and lowland regions. Reclamation of lowlands and wetlands as a result of urbanization also adds to the magnitude of flood damages downstream [3, 4].

There are forty eight reservoirs in the state, which play a major role in flood moderation. Most of the reservoirs are multi-objective in nature with major objectives of power generation and irrigation. The state mainly depends on hydro-electric power to meet the power requirements. Out of the fifteen power projects, seven are located in the Periyar River basin. The regulated releases from these reservoirs decide the streamflow pattern.

When several of the other river basins are subjected to downstream flash floods and associated flood damages during the intense monsoon periods, Periyar river basin with storage reservoirs is an exception. This paper analyzes the role of Idamalayar reservoir, one of the large storage reservoirs in the region, in controlling floods in Idamalayar sub-basin of Periyar basin.

2. Study area

Idamalayar is a tributary of Periyar River and it joins the main Periyar River 1.5 km upstream of Bhoothathankettu barrage (Figure 1). There are seven major hydro electric projects upstream of Bhoothathankettu. Streamflow in Periyar River depends on the operation of the reservoirs of these hydro-electric projects including that of Idamalayar.

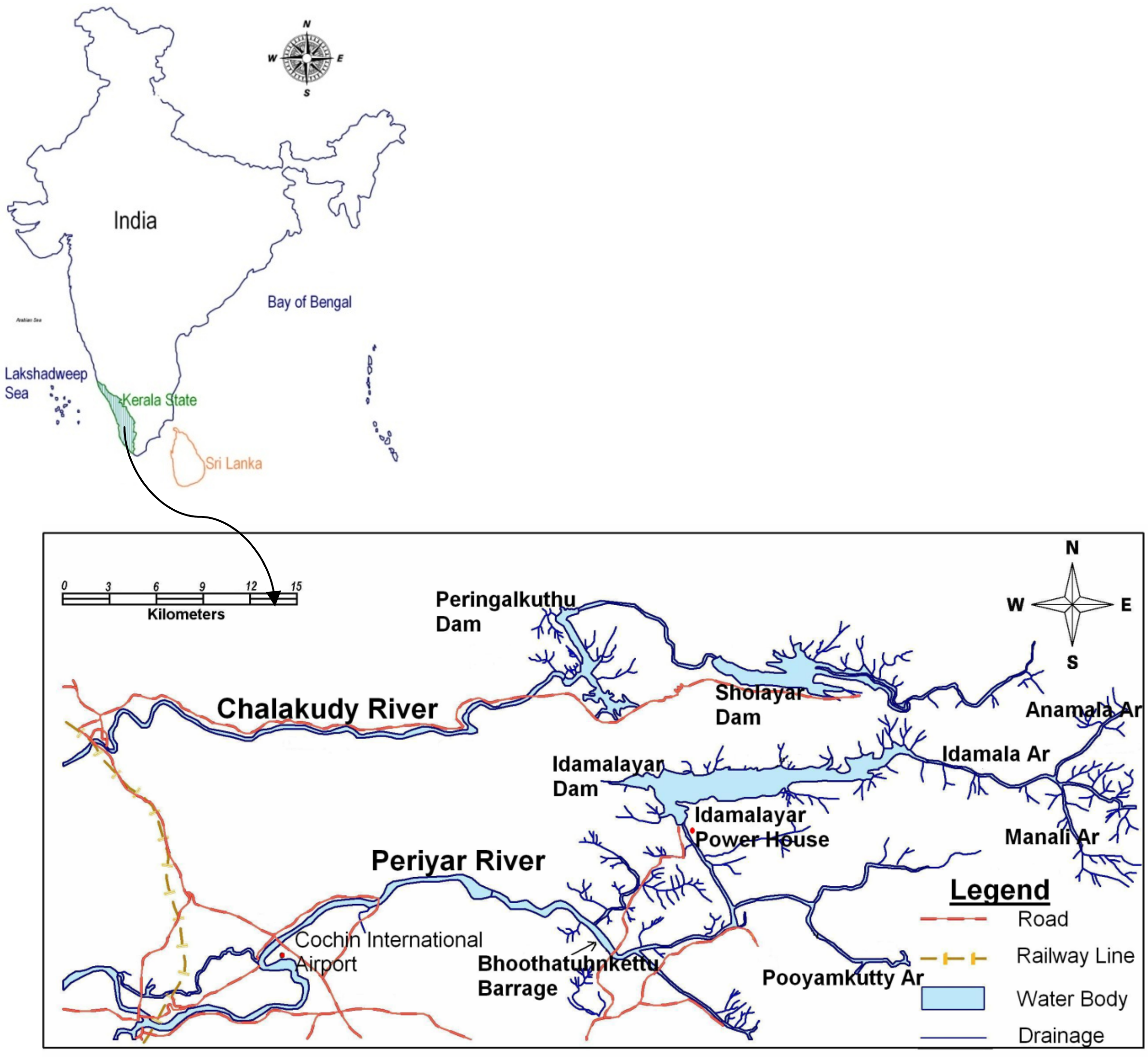


Figure 1. Location map of Idamalayar reservoir

Idamalayar tributary emerges from Anamala in the Devikulam taluk at an elevation of 2520 m above the mean sea level. Anamalayar, Manaliyar and a number of small streams, join together, to form this river (Figure 1). It then flows in a south-westerly direction and the Pooyamkutty tributary finally joins Periyar River at an elevation of +26 m near Koottickal village. The total length of Idamalayar stream up to the confluence with the Periyar is 74 km. Periyar River then flows through the midland and lowland regions, where the major industrial belt of Kerala state is located [4, 9].

Idamalayar reservoir was commissioned in 1987. It is 167 m high concrete gravity dam (latitude 10^0:13':15" N, longitude 76^0: 42': 30" E) with a gross storage capacity of 1024 million cubic meters. The catchment area of the project is 380.73 sq. km.

Idamalayar power house, with an installed capacity of 75 mega watt produces about 600 million units of power annually. The operation of the reservoir is controlled by the Kerala State Electricity Board (KSEB). Standard Linear Operating Policy (SLOP) is generally adopted in which the power generation is directly proportional to the reservoir storage [5]. The salient features of the project are given in Table 1.

Table 1. Salient features of Idamalayar hydro electric project

General Data	Location of dam: longitude: E 76^0:42':30", latitude: N 10^0:13':15"
River Data	Width of river at dam site - 40 m
	Catchment area at dam site- 380.73 sq. km.
Reservoir Data	General bed level of river at dam site: +81.0 m
	Mean annual runoff at Idamalayar dam site: 1369.69 Million cu. m.
	Peak Design flood- 3851 cu m/sec
	Full reservoir level: +169.00 m
	Minimum draw down level: +115 m
	Maximum reservoir level: +170.30 m
	Gross storage at FRL: 1090.80 million cu. m
	Dead Storage below mddl (+115m): 72 million cu. m
	Water Spread area at FRL: 2830 ha
Spillway section	Length of spillway section: 107.50 m
	Spill way crest: +161.00 m
	Radial crest gates: 7 numbers (each of size 11.5 m x 8.5 m)
	Maximum flood discharge capacity: 4063.5 cub m/sec

3. Methodology

The role of Idamalayar reservoir, commissioned in 1987, in flood moderation was analyzed by comparing the daily inflow, outflow and reservoir storage during the period June 1987 to August 2010.
The information on reservoir regime was made available by KSEB. Daily inflow information, storage details, tail race discharge and spill at Idamalayar provided by KSEB were used in the analysis and the inflow and outflow series is compared.
The average monthly inflow, outflow and storage of Idamalayar reservoir along with monthly rainfall at Idamalayar dam site are given in Figure 2.
The Idamalayar catchment contributes about 1406 million m^3 of water to Idamalayar reservoir every year. The peak inflows above return period of 4 years Q_4 (552 m^3 per second) usually occur in the month of August, and the inflow reduces drastically to below 10 m^3 per second by end of December every year. The ratio of reservoir capacity to mean annual inflow is 0.775.

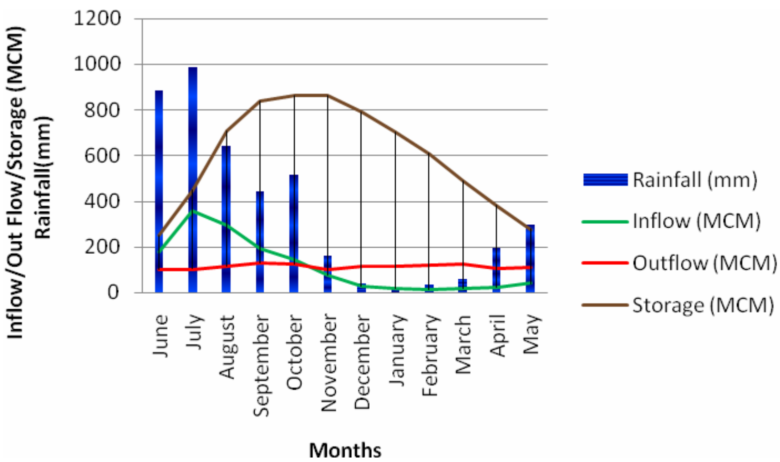


Figure 2. Idamalayar reservoir- monthly average inflow-outflow, storage and rainfall

The water storage levels in the reservoir start rising in the beginning of south-west monsoon in June every year. The storage in the reservoir will be at its peak at the end of north –east monsoon, i.e. by

November. From December to May the storage gradually decreases and the lowest levels are reached in May, the last month of summer season.

3.1 Flood frequency studies

Interpretation of the past hydrologic events in terms of future probabilities of occurrence is one of the most important problems in Hydrology [6]. Hence probabilistic methods have wider application in hydrology especially in flood related analyses. California and Weibull methods are usually used in computation of recurrence interval of floods because of their soundness [7].

Recurrence interval (T) is the reciprocal of probability

$$T=1/P \tag{1}$$

To determine the recurrence intervals, stream flow values at the gauging station is ranked from the highest to lowest (i.e. highest flow with rank 1) using Weibull method recurrence interval (T) of each flow is calculated as:

$$T=(n+1)/m \tag{2}$$

where n is the number of stream flow values ranked and m is the rank number of each stream flow value. Stream flow values and recurrence intervals are plotted with recurrence interval on a logarithmic scale and stream flow values on a linear scale.

The values of annual maximum flood for Idamalayar catchment for 23 successive years, after commissioning of the dam in 1987, were analyzed (Figure 3).

Three types of daily flood flows were identified based on the analysis of daily data. The classification was based on return period of floods (i) 1-2 years return period (ii) 2-4 years return period and (iii) above 4 years return period

(i) Small very frequent floods, with daily discharge above Q_1 (231 m3/sec) but below Q2 (391 m3/sec), in which case the threshold was exceeded on an average of 6 days per year.
(ii) Medium flood flows, with daily discharge between Q_2 (391 m3/sec) and Q4 (552 m3/sec), in which case the threshold exceeded on an average of 2 days per year.
(iii) Large exceptional flood flows, with daily discharges above Q_4 (552 m3/sec), in which the threshold was exceeded on an average of one day per year.

Daily flood flows were used to classify all inflows and outflows. The number of flood days was calculated for both inflow and outflow discharges to understand the seasonal effect [8].

Inflow-outflow hydrographs of Idamalayar reservoir (1987-2010) were compared with hydrographs used for design (1943-1968). Weighted average rainfall information (Thiessen Polygon Method) from fifteen rain gauge stations in and around Idamalayar catchment was the major input in arriving at the inflow hydrograph for the period 1943-1968. Inglis' rainfall runoff straight line relationship for Western Ghat region was used to compute monthly inflow hydrograph for Idamalayar reservoir. The results were validated by comparing rainfall-runoff relationship of contiguous and similar Pooyamkutty catchment and the gauged data for a period of six years [9]. Pooyamkutty is a major tributary of Idamalayar joining Idamalayar downstream of Idamalayar Dam.

3.2 Non-parametric trend analysis

MAKESENS(Mann-Kendall test for trend and Sen's slope estimates) excel template [10] was used to identify the south-west and north-east inflow and storage trends for 1943-68, 1987-2010 and 1943-2010 periods. The Mann-Kendall test is applicable in cases where the data values x_i is assumed to obey the model

$$x_i=f(t_i)+\varepsilon_i \tag{3}$$

where f(t) is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with zero mean. For the time series with less than 10 data points the S test is used and for time series with 10 or more points the normal approximation (Z statistics) is used. A positive value of Z indicates a downward trend. Four significance levels (α) are tested in MAKESENS. They are 0.001, 0.01, 0.05 and 0.1. In all other cases, the significance level is greater than 0.1.

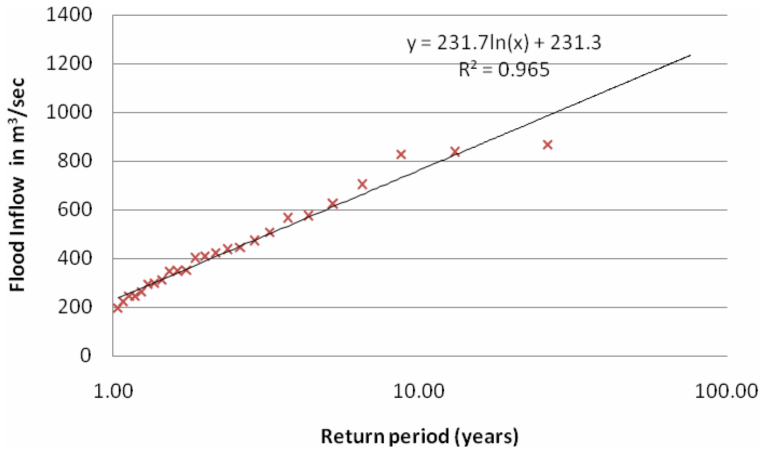


Figure 3. Annual peak flows-return period at Idamalayar

4. Results and discussion

4.1 Seasonal regime

Average monthly inflow-outflow curve of Idamalayar reservoir (Figure 2) very clearly shows that peak monsoon discharge during June - August is absorbed by the reservoir. The water storage level will be the lowest in May and will starts rising in June and reaches the peak in November. After this period there, is considerable reduction in inflow and a rise in power generation due to increased summer demand. This leads to lowering of water levels which reaches the lowest level by May end. The cycle repeats every year. During lean flow period, inflow to reservoir is usually less than outflow. This is because the inflow during summer season (December-May) goes below the minimum release for power generation. A relatively stable outflow of about 30-58 m^3/sec can be noticed in the outflow curve, which is the usual release range to Idamalayar power house to meet the power demands (Figure 2).

4.2 Moderation of floods with varying intensity and frequency

Frequency- intensity curve showing the ranked inflow to Idamalayar reservoir and ranked outflow after power generation/spill is given in Figure 4. Return period for flood inflow and flood outflow as well as corresponding reduction (%) is shown in Figure 5. Based on the return period analysis of peak flood inflows, utilizing the daily data of 1987-2010, flood reduction (%) was estimated based on corresponding outflows (Figure 5). Outflow corresponding to peak flood inflow shows no correlation and more than 80% flood reduction is achieved for all the flood events considered in the analysis. This higher value of flood moderation was because of the fact that most of the flood events considered for the analysis, occurred during July-August when the reservoir storage was less than 70%.

4.3 Role of water storage levels

Flood moderation capacity of Idamalayar reservoir, with a live storage capacity up to Full Reservoir Level (FRL) of 1017.80 million m^3, was analyzed at three storage ranges (below 50%, 50-90% and above 90%). The analysis was done for flood events greater than 231 m^3/sec (Q_1) for the period 1994-2010.

During the second half of summer period (March – May), the reservoir water levels are the lowest, making the reservoir capable of absorbing the south–west monsoon discharge during June - August. Figure 6 (a) shows that the inflow and outflow curves separate very rapidly, as the probability of excedence increase. It is also noted that the outflow is almost constant, which in many years is ruled by the power requirement. The floods below 50% reservoir levels are completely absorbed by the reservoir. Reduction in outflow was 73 -96%.

For storage level range of 50-90%, the reduction pattern was almost similar to that of below 50%, showing complete absorption of flood discharge. The reduction in outflow in this case was 68-97% (Figure 6 (b)). For floods events above 90% storage levels, buffering of flood intensity downstream, on several occasions, didn't materialize causing spills. Flood reduction in this case varied widely between 0-96% depending on the storage condition (Figure 6(c)).

Graphs of ratios of inflow and outflow for different storage levels show that, flood moderation is less when reservoir storage levels are higher. For different flood magnitudes, the slope varies as detailed in

Figures 7a to 7c. The coefficient of determination is higher for large floods compared to medium and small floods, showing that for large floods, the flood moderation is more related to reservoir storage.

4.4 Monthly frequency of peak flows

Figure 8 shows monthly frequency of peak flows, taking into consideration daily flow data for 19 years (1993-2010). Daily inflow and outflow peaks with three flood intensity levels (Q_1-Q_2 (231-391 m^3/sec), Q_2-Q_4 (391-552 m^3/sec), and above Q_4 (>552 m^3/sec)) were considered for the analysis. Most of the floods occur during south-west monsoon period (July-August) (Figure 8(a)). The flood events downstream of the reservoir (intensity between Q_1-Q_2) were noticed only during August and September when the reservoir storage was at its peak. Spills occurred only during five out of twenty four years; during all other times, floods were very well managed downstream. The releases from the reservoir were mainly dependant on the power requirements.

4.5 Comparison of reservoir design (1943-1968) & actual hydrographs (1987-2010)

Reservoir inflow and outflow hydrographs (monthly) used during design of reservoir (1943-1968) was compared with actual inflow outflow hydrograph (Figure 9 (a) & (b)). The inflow hydrograph (1987-2011) shows a reduced inflow during south-west monsoon and increase in inflow during north-east monsoon compared to design inflow hydrograph. The outflow hydrograph shows increase during September-March.

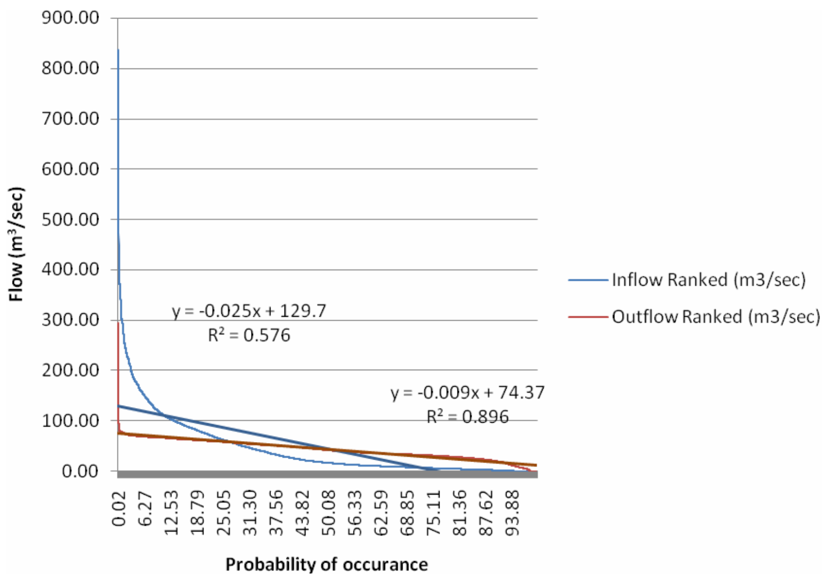


Figure 4. Inflow – outflow- frequency-intensity curve

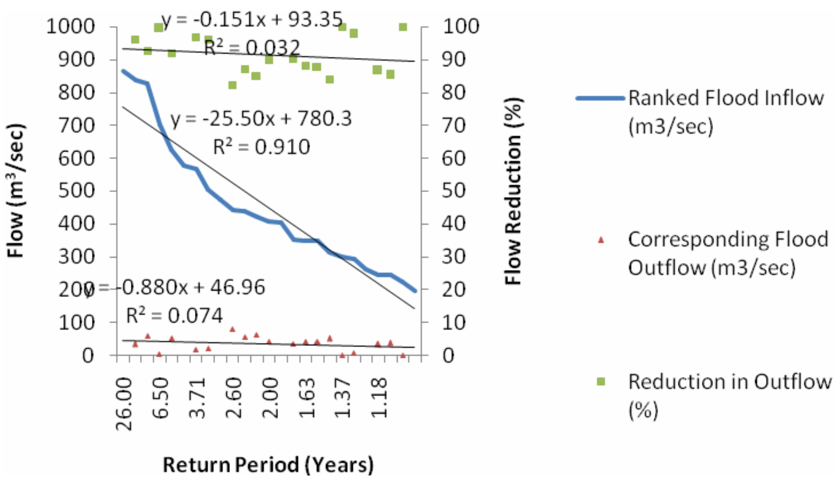
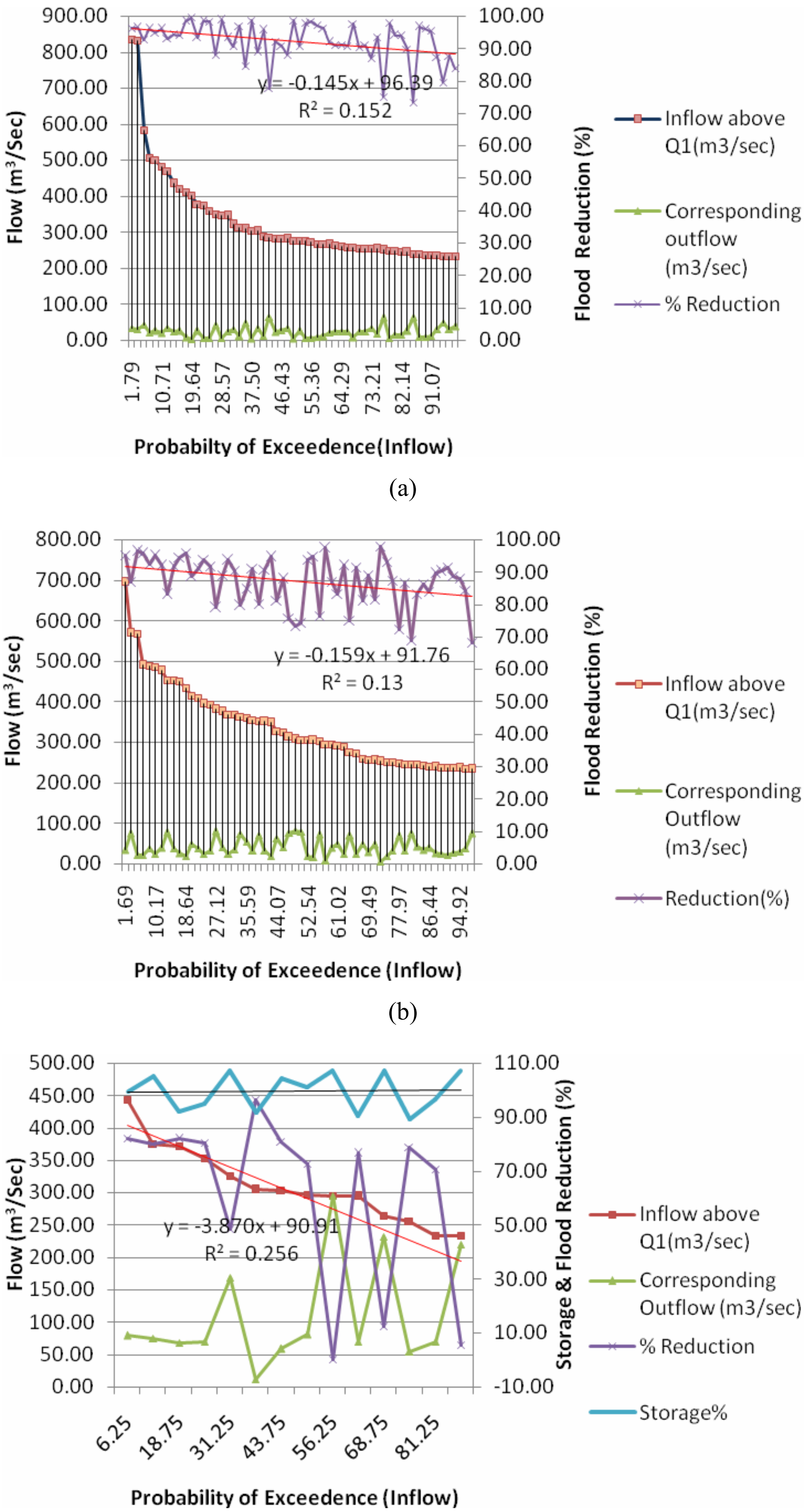


Figure 5. Recurrence intervals of flood inflow and corresponding outflow

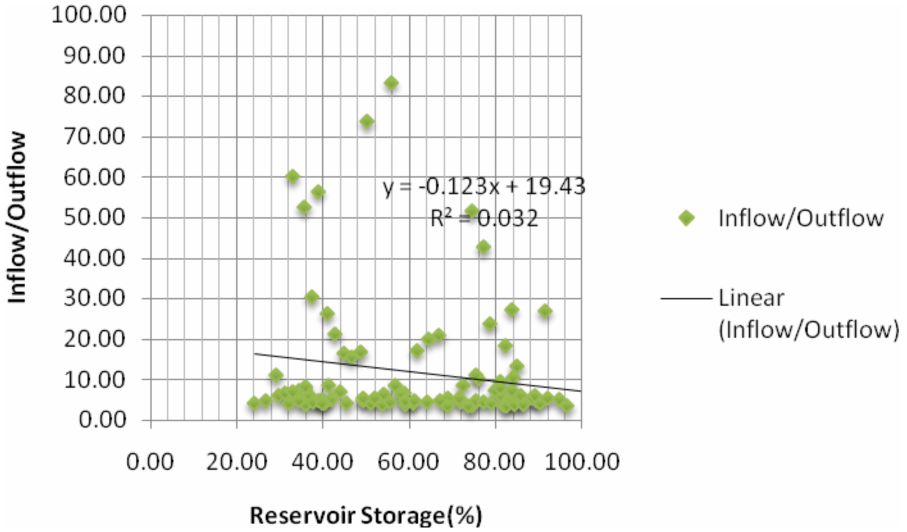


(a)

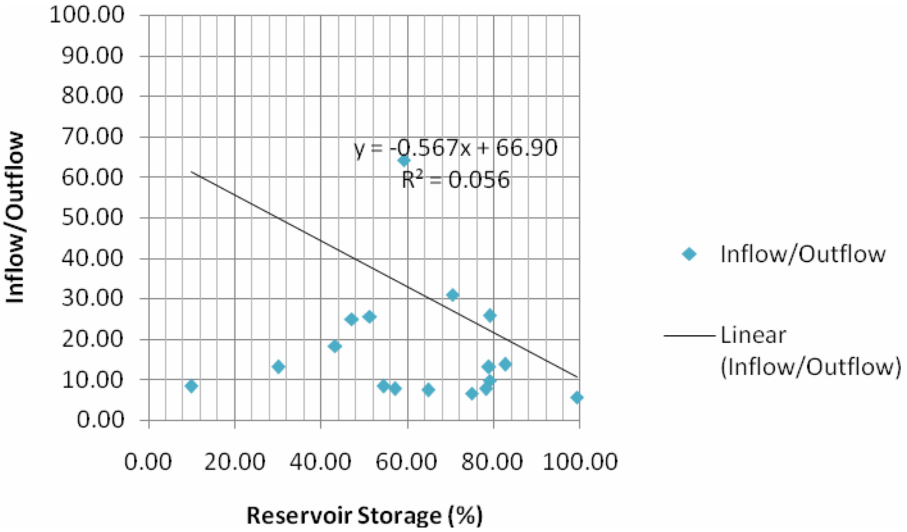
(b)

(c)

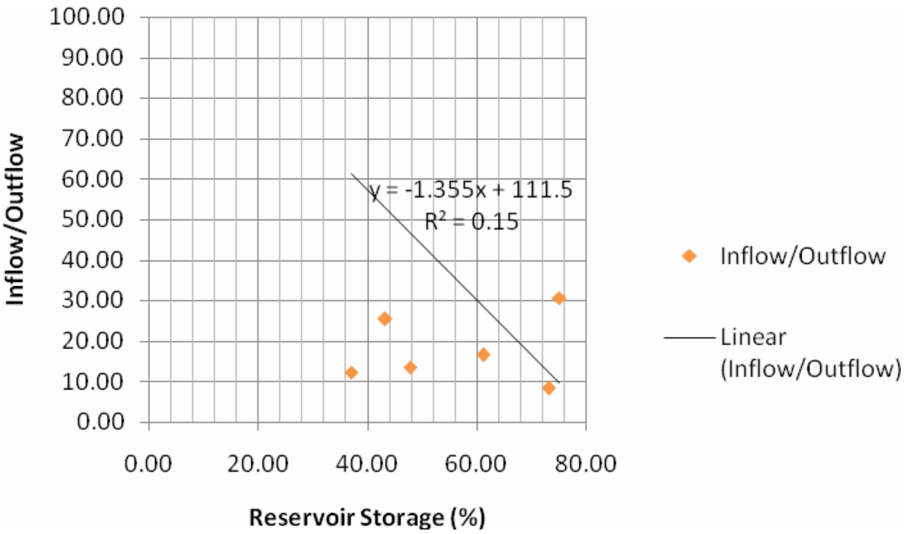
Figure 6. (a) Reservoir storage less than 50-90%; (b) Reservoir storage less than 50-90%; (c) Reservoir storage above 90%



(a) Floods between Q1 and Q2

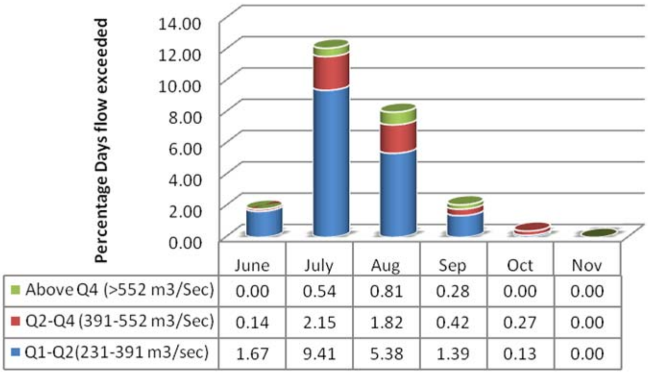


(b) Floods between Q_2 and Q_4

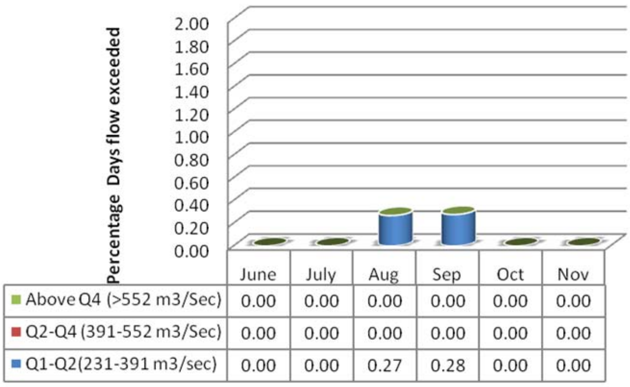


(c) Floods above Q_4

Figure 7. Ratio of inflow peaks and corresponding outflows in relation to reservoir storage

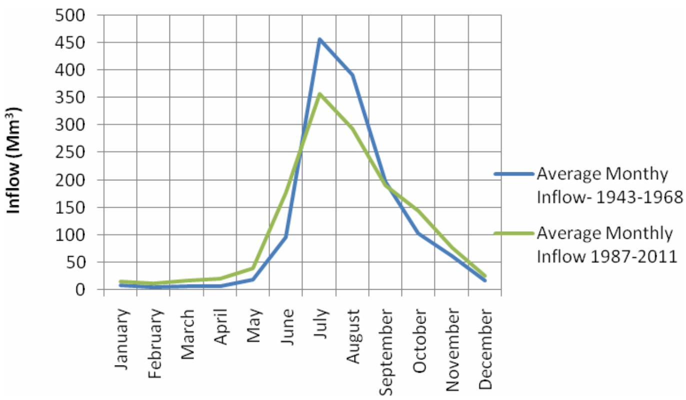


(a)

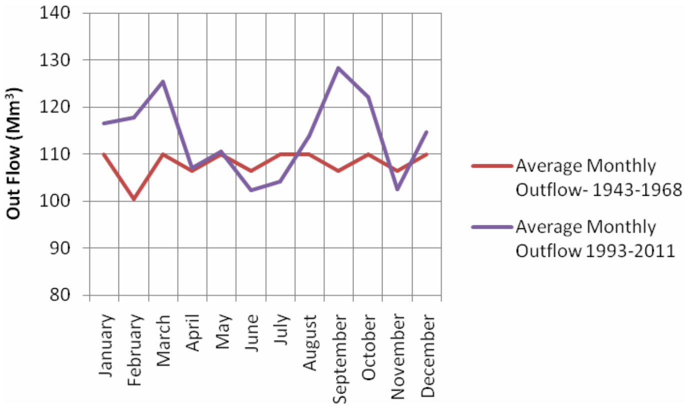


(b)

Figure 8. (a) Inflow Peaks-percentage time exceeded; (b) Outflow Peaks-percentage time exceeded



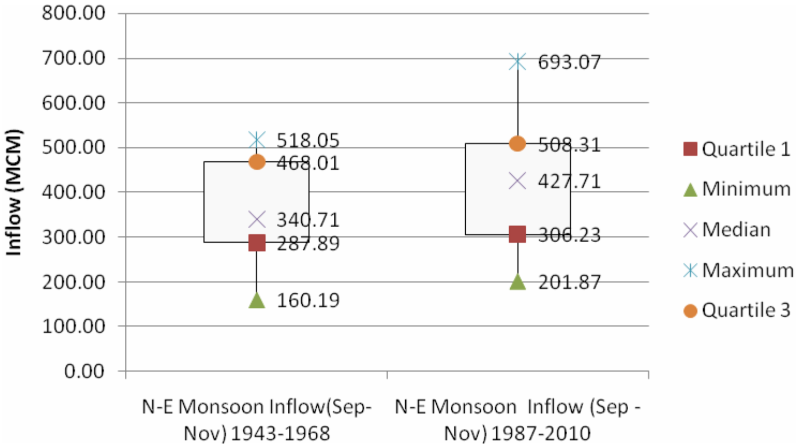
(a)



(b)

Figure 9. Average monthly inflow and outflow

Box-Wisker plots comparing south-west monsoon and north-east monsoon inflow during the design period and after commissioning of dam are shown in Figure 10 (a) and (b). Average south-west monsoon and north-east monsoon storage during 1943-68 and 1994-2010 are detailed in Table 2.



(a) (b)

Figure 10. Statistics on south-west and north-east monsoon inflows

Table 2. Statistics on average reservoir storage during south-west and north-east monsoons

Statistics	Average S-W Monsoon Storage 1943-68	Average S-W Monsoon Storage 1994-2010	Average N-E Monsoon Storage 1943-1968	Average N-E Monsoon Storage 1994-2010
Quartile 1	805.94	723.62	287.89	306.23
Minimum	556.54	436.44	160.19	201.87
Median	877.40	811.69	340.71	427.71
Maximum	1589.29	1157.51	518.05	693.07
Quartile 3	955.42	947.26	468.01	508.31

4.6 Analysis of spill

Comparison of spill data based on reservoir working table prepared using data of 1943-1968 show that spill frequency and magnitude after commissioning of reservoir has come down considerably (Figure 11). Average monthly storage levels (1987-2010) in second half of summer (March-May) and during north-east monsoon (September-November) are found to be less than the storage values worked out using 1943-1968 data.

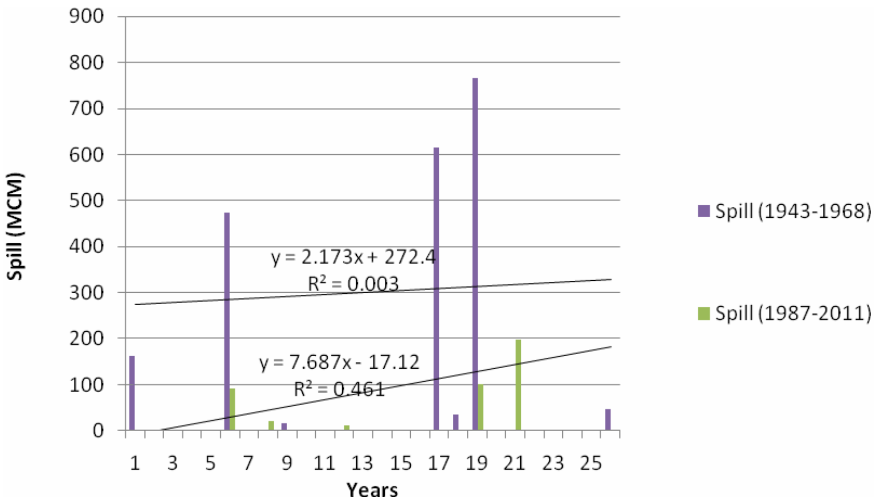


Figure 11. Annual spill from Idamalayar reservoir

4.7 Mann-Kendall trend statistics

Trend statistics computed for inflow and storage for the design period (1943-68) and for the period after commissioning of the reservoir (1987-2010) are given in Table 3.

The analysis predicts a decreasing trend for south-west monsoon inflow. North-east monsoon inflow for the period 1943-68 shows a decreasing trend and the trend changes to positive during 1987-2010 periods. Reservoir storage for all the periods of analysis show negative trends.

Table 3. Mann-Kendall trend statistics of inflow & reservoir storage

Time Series	First Year	Last year	n	Test Z
		Inflow		
South-West Monsoon	1943	1968	26	-0.22
South-West Monsoon	1987	2010	24	-0.17
South-West Monsoon	1943	2010	50	-1.17
North-East Monsoon	1943	1968	26	-0.53
North-East Monsoon	1987	2010	24	+1.17
North-East Monsoon	1943	2010	50	+1.29
		Reservoir Storage		
South-West Monsoon	1943	1968	26	-0.35
South-West Monsoon	1994	2010	17	-0.62
South-West Monsoon	1943	2010	43	-0.44
North-East Monsoon	1943	1968	26	-0.22
North-East Monsoon	1994	2010	17	-0.54
North-East Monsoon	1943	2010	43	-1.36

5. Conclusions

The role of Idamalayar reservoir in flood moderation and the seasonality of floods in the humid tropical region of Kerala were studied. The analysis show that floods are moderated efficently by the reservoir.

1. Flood moderation by Idamlayar reservoir in depends on (1) time of occurance of flood event (2) storage level of reservoir (3) intensity of flood
   a) Since the reservoir situated in humid tropics is refilled during south-west monsoon period, there is a clear reduction in the number of floods downstream during that period.
   b) The chances of flood events downstream are more during north-east monsoon period (September-November) when the reservoir storage level is at its peak.
   c) The role of reservoir in moderating floods is more related to water storage levels for large flood when compared to medium and small floods. Floods are very well controlled when the reservoir capacity is less than 50%. Between 50% and 90% and above 90% capacity, flood control depends on storage levels of the reservoir.
2. Over a period of 50 years changes are noticed in inflow, out flow and storage
   a) Trend analysis of inflow to reservoir shows a decreasing trend during S-W monsoon and an increasing trend during N-E monsoon period. Such a decresing trend in inflow imporved the efficeny of flood moderation.
   b) Outflow from the reservoir during September –March shows an increase, due to increased power requirement and water demands downstream.
   c) Storage during both the monsoon periods show decreasing trend.
3. Comparison of spill calculated for the period 1943-1968 and the actual spill data (1987-2010) show that magnitude and frequency of spill from the reservoir was less after commissioning of the reservoir.
4. Changes in the inflow and storage pattern during the S-W and N-E monsoon periods and the higher outflow during September –March is the contributing factor for reduced spill more efficient flood moderation by the reservoir.

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